Space Surveillance Working Group
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Source of Acquisition
NASA Goddard Space Flight Center

Status of the NASA Robotic Mission Conjunction Assessment Effort

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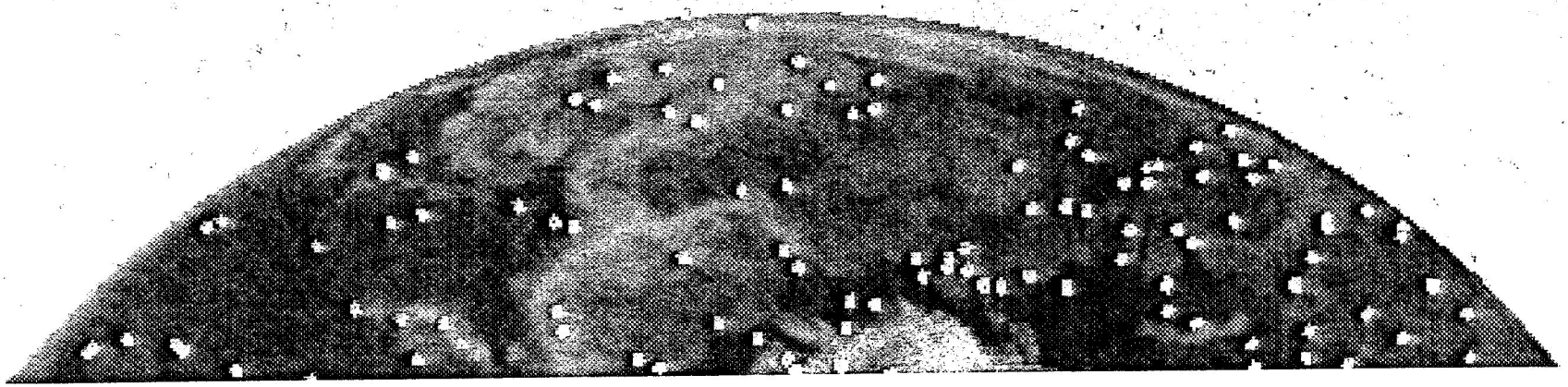

Agenda

- Background
- Goddard Stakeholders and Mission Support
- ESC and TDRS Mission Descriptions
- TDRS Conjunction Assessment Process
- ESMO Conjunction Assessment Process
  - Risk Assessment
  - Risk Mitigation
- Recent Operations Experiences
- Statistics Collected for ESC Regime
- Current & Future Analysis Items

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Background 1/3

- The collision risk due to orbital debris is increasing:
  - ~11,000 tracked objects >1 cm^2
  - There have been 3 collisions publicly documented; all events occurred in low earth orbit, 1 near ESC regime
  - Several hundred objects are being added to catalog each year (Ref Liou & Johnson)
- Recent events such as the Chinese ASAT test and the Breeze-M rocket explosion have led to greater community awareness and concern
  - Demonstrates the necessity of an operations concept that includes monitoring, computing and mitigating collision risks

Background 2/3

- Routine (daily) close approach predictions are made for numerous DoD and NASA assets
  - Collision risk assessment analysis considered a critical component of orbital safety for DoD
  - NASA currently has no requirement regarding Conjunction Assessment (CA); individual Flight Projects implement programs for risk mitigation using available resources
- Existing NASA CA Programs:
  - NASA/JSC performs CA for Human Space Flight assets 3 times a day
  - NASA/GSFC performs routine assessments for 11 Earth Science Constellation satellites and 9 TDRS satellites

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Background 3/3

- Routine conjunction assessment began in January 2005 for TDRS and Aqua/Aura. Remaining ESC missions added incrementally over 6 month period
- Cheyenne Mountain 1st SPCS NASA GSFC-dedicated Orbital Safety Analysts (OSA) perform screening for Goddard
- Governing Documents are:
  - "Memorandum of Agreement between DoD and NASA for Support to NASA Spaceflight Operations"
  - Support Agreement between Air Force Space Command and Goddard Space Flight Center
  - Interagency Operating Instruction (draft): Describes the products exchanged between 1stSPCS and GSFC

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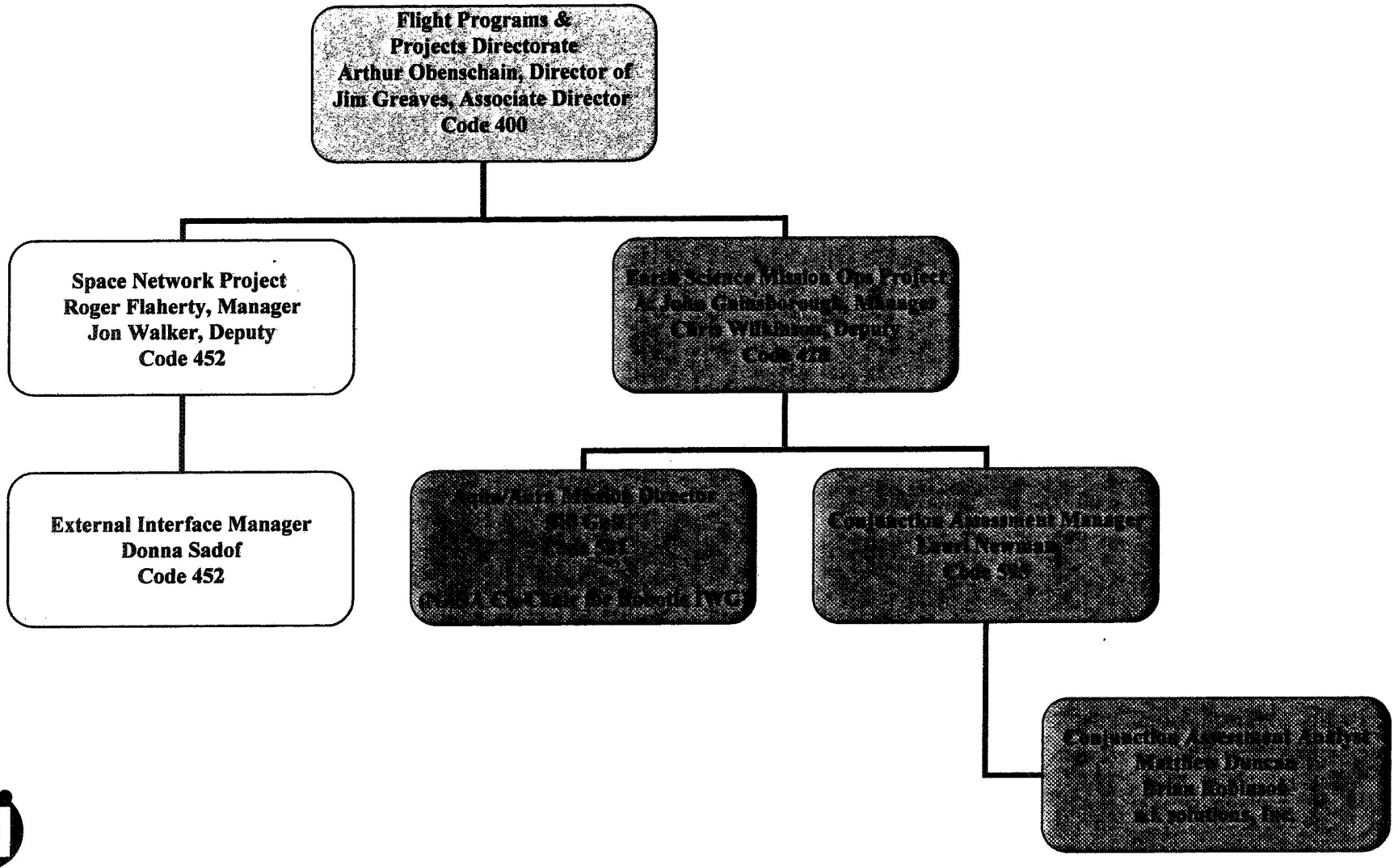
GSFC CA Principal Parties



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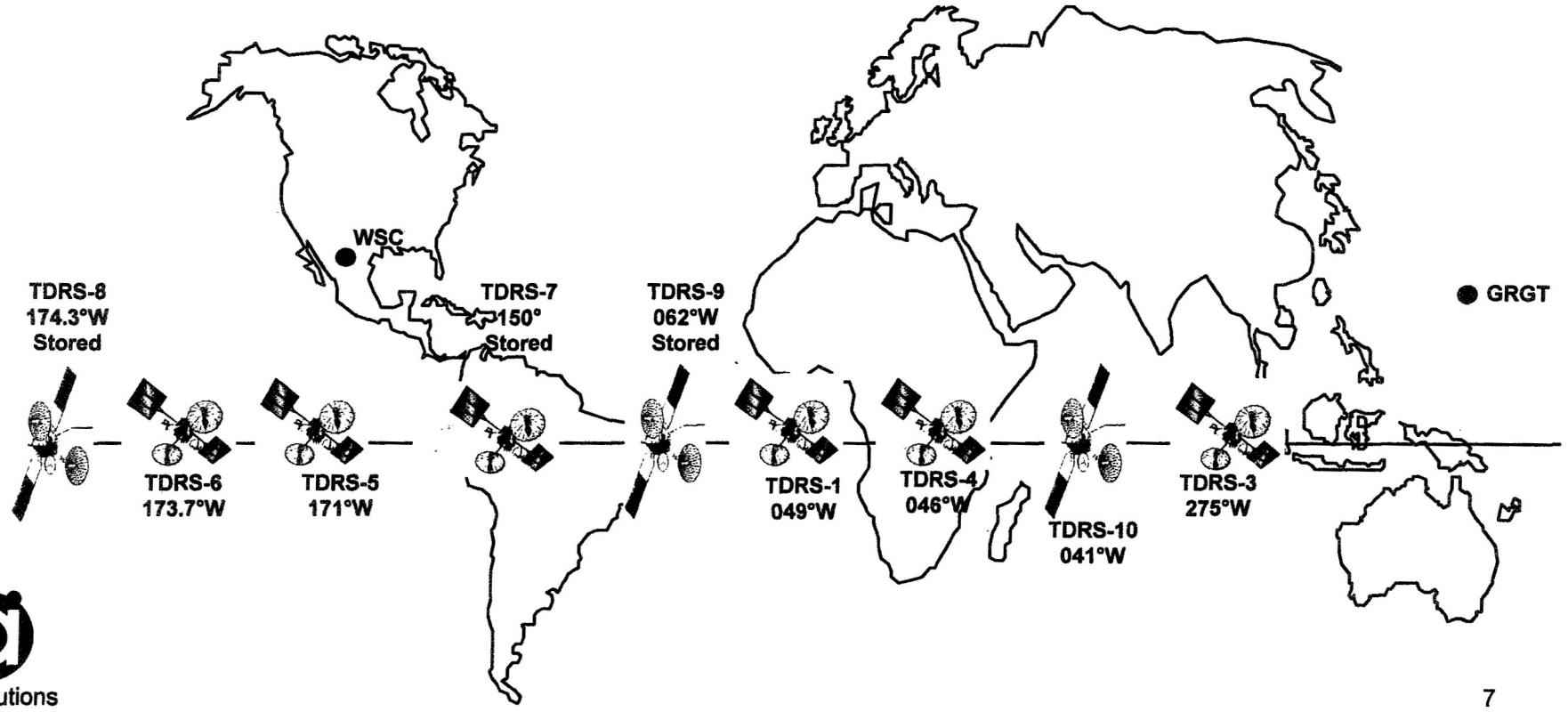
TDRS System Description

- Relay system composed of ground systems and nine spacecraft in geosynchronous orbit positioned at various longitudinal slots about the Earth.



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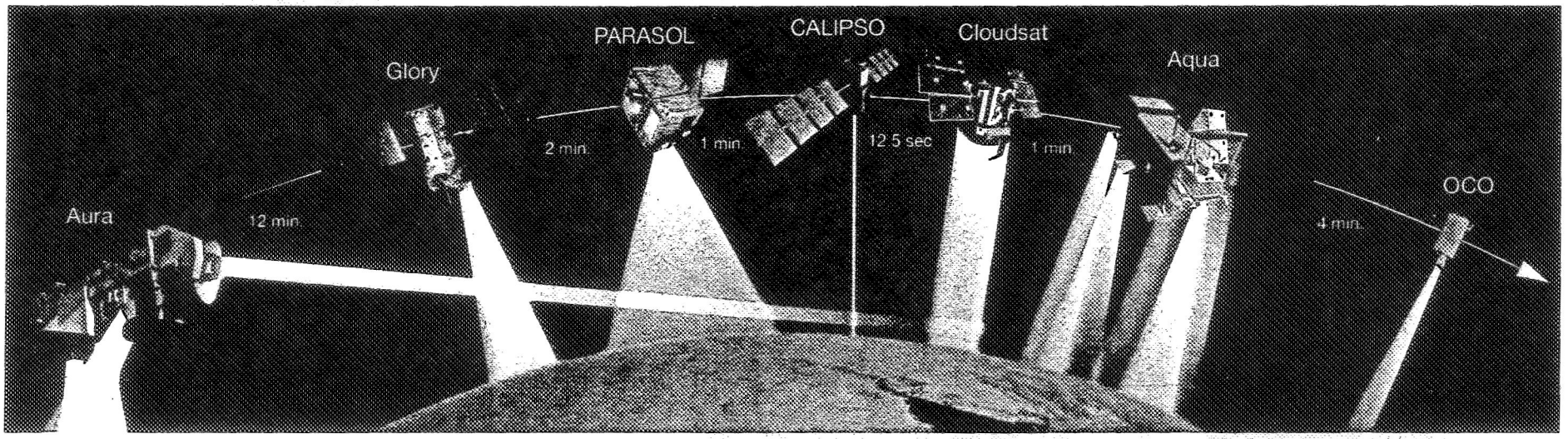
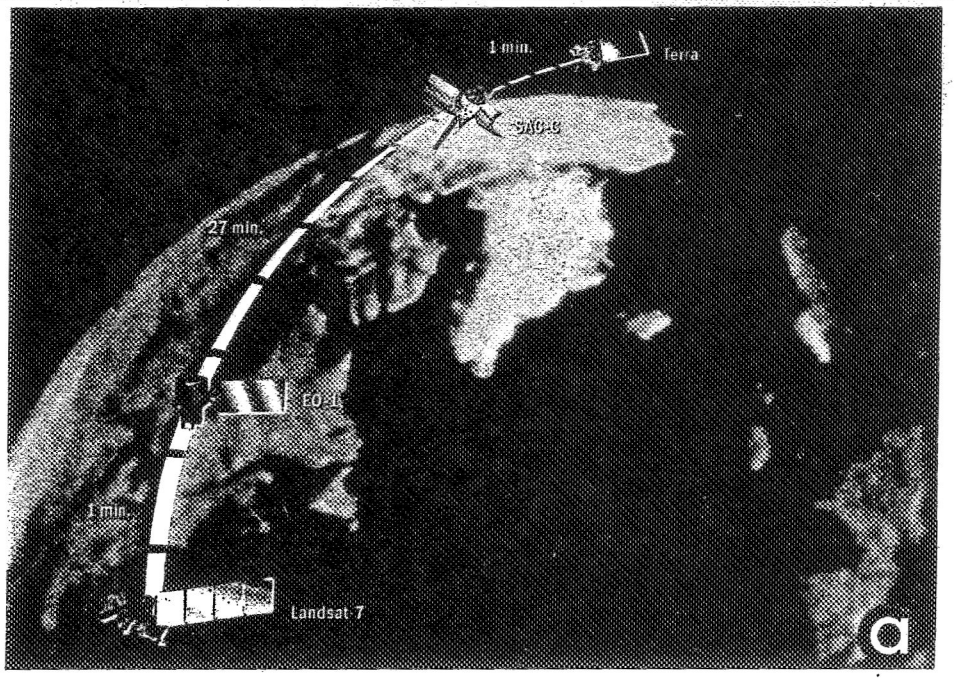
Earth Science Constellations



- Combination of NASA and FSO assets
- Each mission makes its own risk mitigation decisions
- Each mission subject to own maneuverability, comm, and ops concept constraints



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1st SPCS Screening Process for Goddard

- Screenings performed daily (weekends as needed) using the high accuracy (Special Perturbations) catalog
- Predictions are made 7 days into the future.
- Both Owner/Operator and Cheyenne Mountain - derived ephemeredes are processed for the primary objects of interest.
  - Any planned maneuvers are modeled in the Owner/Operator ephemeredes.

TDRSS CA Process

TDRS CA Process

- All conjunctions predicted to pass within a 40-km stand-off radius of a TDRS are reported by 1SPCS to Stakeholders.
  - Conjunctions with total predicted misses less than 40 km, but greater than 15 km are referred to as "Monitor" conjunctions.
  - Conjunctions with total predicted misses less than 15 km are Alert Conjunctions, and are graded as follows:

Alert Condition Code	Minimum Predicted Separation
Yellow	5 km < Total Miss < 15 km
Orange	2 km < Total Miss < 5 km
Red	0 km < Total Miss < 2 km

- **Orange** and **Red** alert conjunctions are candidates for evasive maneuver planning
  - Screening frequency increased to at least daily
  - NASA considers and potentially plans a collision avoidance maneuver
  - Space Segment Manager makes the final decision

ESMO CA Process

ESC Safety Volumes

- Three different mission safety volumes define data product delivery from 1st SPCS and data processing from EOS CA team
- The safety volumes are expressed in the primary UVW coordinate frame: U (radial), V (in-track) and W (cross-track)
- **Monitor Volume** (ellipsoid) +/- 2 x 25 x 25 km
  - Largest filter used to initially identify and report potential close approaches
- **Tasking/Alert Volume** (box) +/- 0.5 x 5 x 5 km
  - Serves as a second warning and an elevated level of concern
  - Tasking level on the secondary object is increased (if necessary)
- **Watch Volume** 1 km standoff distance

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Data Products from 1st SPCS

- All Monitor Volume violations are summarized in a Conjunction Summary Report and delivered to the CA SFTP server. The Summary Report contains:
  - Time of Closest Approach (TCA)
  - Total Miss Distance
  - Miss Distance Position and Velocity Components in RIC frame
- An Orbital Conjunction Message (OCM) is provided for Tasking/Alert Volume violations. The OCM contains:
  - TCA
  - Asset State/Covariance at TCA
  - Object State/Covariance at TCA
  - Other orbit determination information helpful in performing collision risk assessment.
- Vector Covariance Messages (VCMs) for both objects are provided for Watch Volume violations.
  - VCMs contain epoch state and covariance information
  - Used for maneuver planning

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The Collision Assessment System

- Collision Assessment System (CAS) was developed to store and analyze the large volumes of data received.
- CAS is automated and comprised of several elements:
  - Secure File Transfer Protocol Server
  - Parser / Monitor Scripts
  - Database
  - Collision Assessment and Mitigation (CAM) Tool Suite
  - Secure Website
  - Configuration Management System
- 1st SPCS posts data products to the SFTP site.
- CAS automatically parses the data and puts it into the database for trending and use with other tools
- The CAM Tool Suite is run each time new data is received
- A summary report is generated containing all pertinent information and delivered to stake-holders.

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Collision Assessment and Mitigation Tool Suite

- The CAM Tool Suite is the part of CAS that provides analysis utilities
- The CAM Tool Suite consists of 6 modules:
  1. Conjunction Visualization Script
  2. 2-D Collision Probability Utility
  3. Monte Carlo Simulation
  4. 3-D / Curvilinear Collision Probability Tool
  5. Time History Trending Utility
  6. Collision Avoidance Planning Tool
- The modules are built using FreeFlyer™ and Matlab™
- Output from tools is formatted into a single PDF report for each OCM

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Screening Data Processing

- Conjunction Summary Report Processing:
  - Overlap compare computes differences between subsequent solutions for the same close approach
  - 1st SPCS and Owner/Operator solutions are compared
  - Results are posted to the EOS Portal
- A CA Calendar is produced and posted to the Portal
  - Contains close approach predictions of less than 1 km, events having P_c > 1e-7, and planned maneuver dates/times.
- CA Analyst examines all data on Portal daily to produce a "watch list" of events warranting further analysis.

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Sample Watch List

11-01-2006 Conjunction Watch List

Primary v Secondary	TCA	Action	Comments
Landsat-5 v 87893	11/02/06 17:25	Not a threat	Large miss distance.
Landsat-7 v 26181	11/04/06 13:39	Monitor	Will monitor updates to the OD on both objects.
Terra v 10525	11/04/06 16:43	Not a threat	Large miss distance.
SAC-C v 22577	11/03/06 10:08	Not a threat	Miss distance is much larger than position uncertainty.
SAC-C v 81168	11/05/06 17:20	Not a threat	Large miss distance.
Aura v 478	11/04/06 15:13	Not a threat	Large miss distance.
Parasol v 82104	11/06/06 21:02	Not a threat	Large miss distance.
CloudSat v 06173	11/06/06 07:03	Not a threat	Large miss distance.
CloudSat v 29054	11/06/06 21:50	Not a threat	Large miss distance.

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Risk Assessment

- P_c and miss distance data alone cannot be used to fully assess the threat
  - The P_c can be "high" even with large miss distances – this is typically due to very large position uncertainties.
    - Although mathematically "correct", the P_c is not necessarily representative of the collision threat
    - The decision to maneuver can be very difficult
- Close approach events are evaluated by analyzing :
  - Orbit determination (OD) consistency from solution to solution
    - Number of tracks and observations
    - Ballistic Coefficient
    - Solar Radiation Pressure Coefficient
    - Energy Dissipation Rate
    - Radar Cross Sectional Area
  - P_c and P_c sensitivity analysis
  - Conjunction Geometry (clock angle, approach angle)
  - Position of hard body radius with respect to the 3-sigma covariance ellipse

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Risk Mitigation

- If the threat evaluation indicates the need to plan and (possibly) execute a maneuver:
  - Maneuver must sufficiently increase the separation distance and decrease the collision probability
  - Maneuver must meet orbit requirements if at all possible
- The maximum delta-V that will maintain control box requirements is obtained from the Flight Operations Team.
- Several maneuver options are generated and weighed against mission constraints
  - Vary the maneuver execution time with a fixed delta-V
  - Vary the delta-V for a fixed maneuver execution time
- Results are plotted; the best maneuver is chosen based on:
  - the successful mitigation of the conjunction
  - the minimum delta-v necessary
  - the effect on consecutive conjunctions with the same object
- Sensitivity of P_c to variations in burn performance is analyzed

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Maneuver Planning Process

- Maneuver planning begins ~ TCA-3 days
  - As TCA approaches, uncertainty decreases, but avoidance options decrease
- Allows time to:
  - Improve the OD solution on the secondary object
  - Evaluate several maneuver options
  - Have 1st SPCS screen the options for post-maneuver close approaches
  - plan the final maneuver
  - Upload commands to the spacecraft

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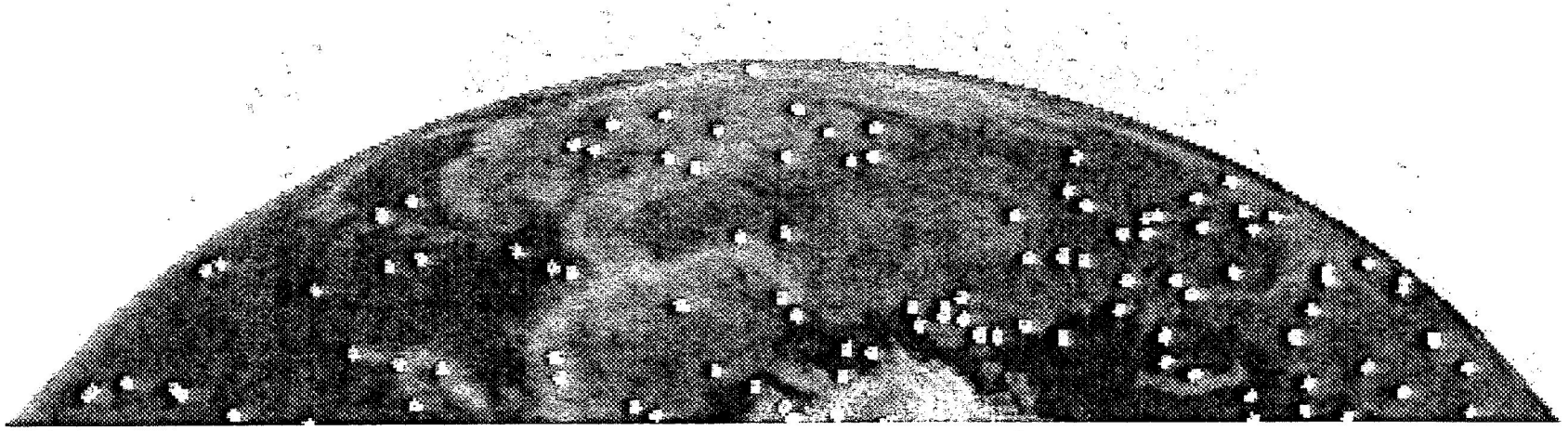
Operations Experiences

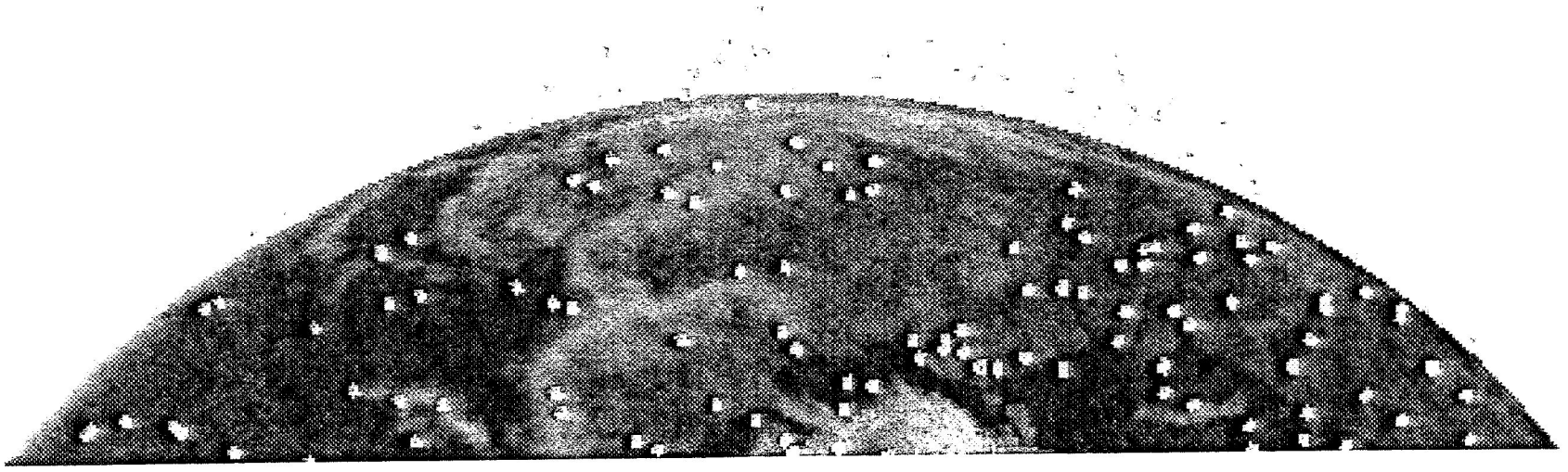
- Actions taken to date (1/05-2/07):
  - Aqua Ground Track Maintenance Maneuver waived off (5/05)
  - Terra Risk Mitigation Maneuver executed (10/05)
  - Aqua Ground Track Maintenance Maneuver waived off (12/05)
  - Terra Ground Track Maintenance Maneuver waived off (1/06)
  - TDRS Risk Mitigation Maneuver executed (1/06)
  - PARASOL Risk Mitigation Maneuver executed (1/07)
  - SAC-C Risk Mitigation Maneuver executed (2/07)

- Automation is essential for managing the workload of routine data processing
- Personnel experienced in orbit determination are required to assess the threat using multiple criteria
- Each event appears to be sufficiently unique such that a standardized mitigation approach cannot be adapted
- Each spacecraft sees a handful of conjunctions per year for which avoidance maneuver planning is considered

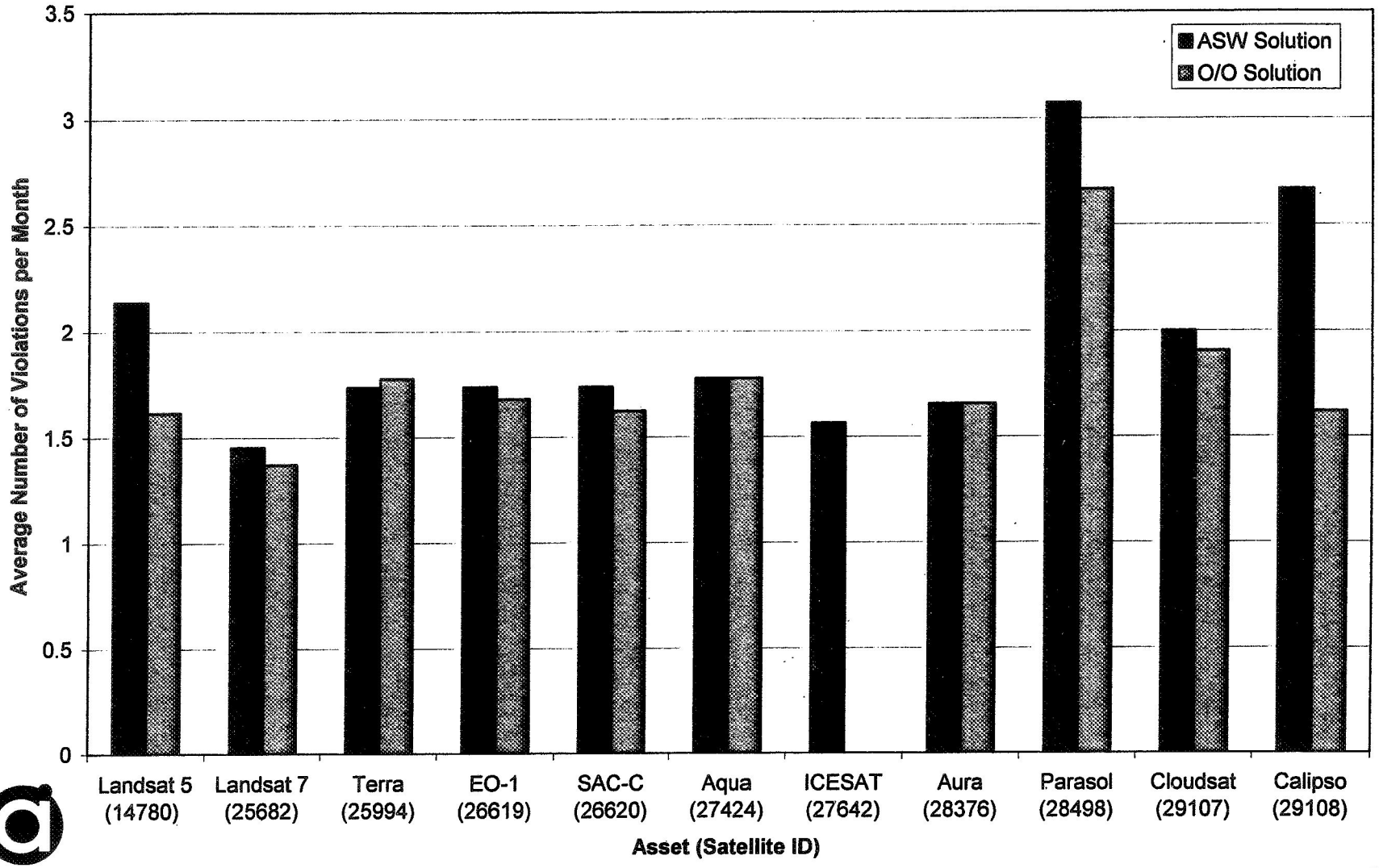
Earth Science Constellation Conjunction Statistics



All Objects



Average Number of Predicted Violations <1km per Asset per Month



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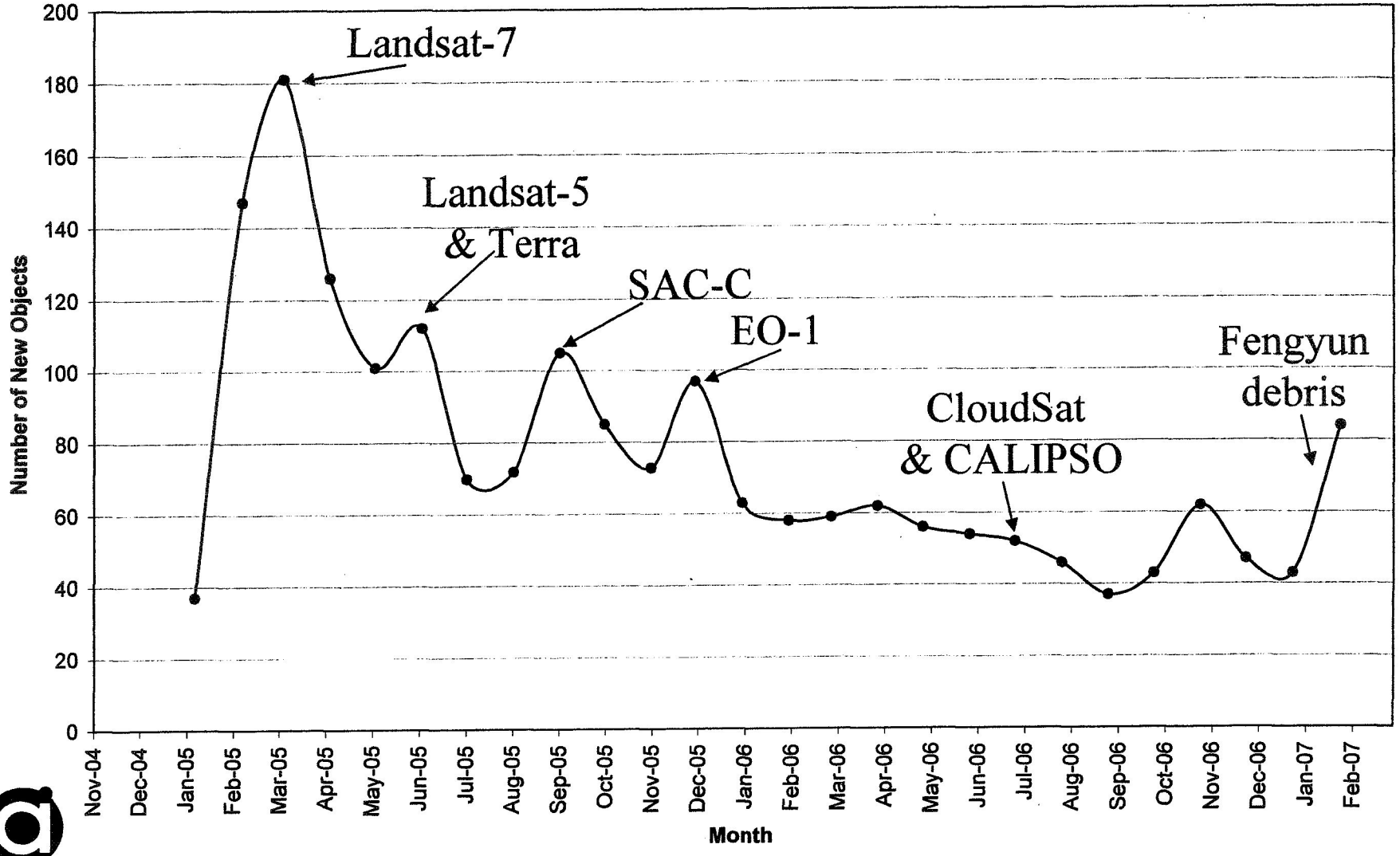
New Objects per Month



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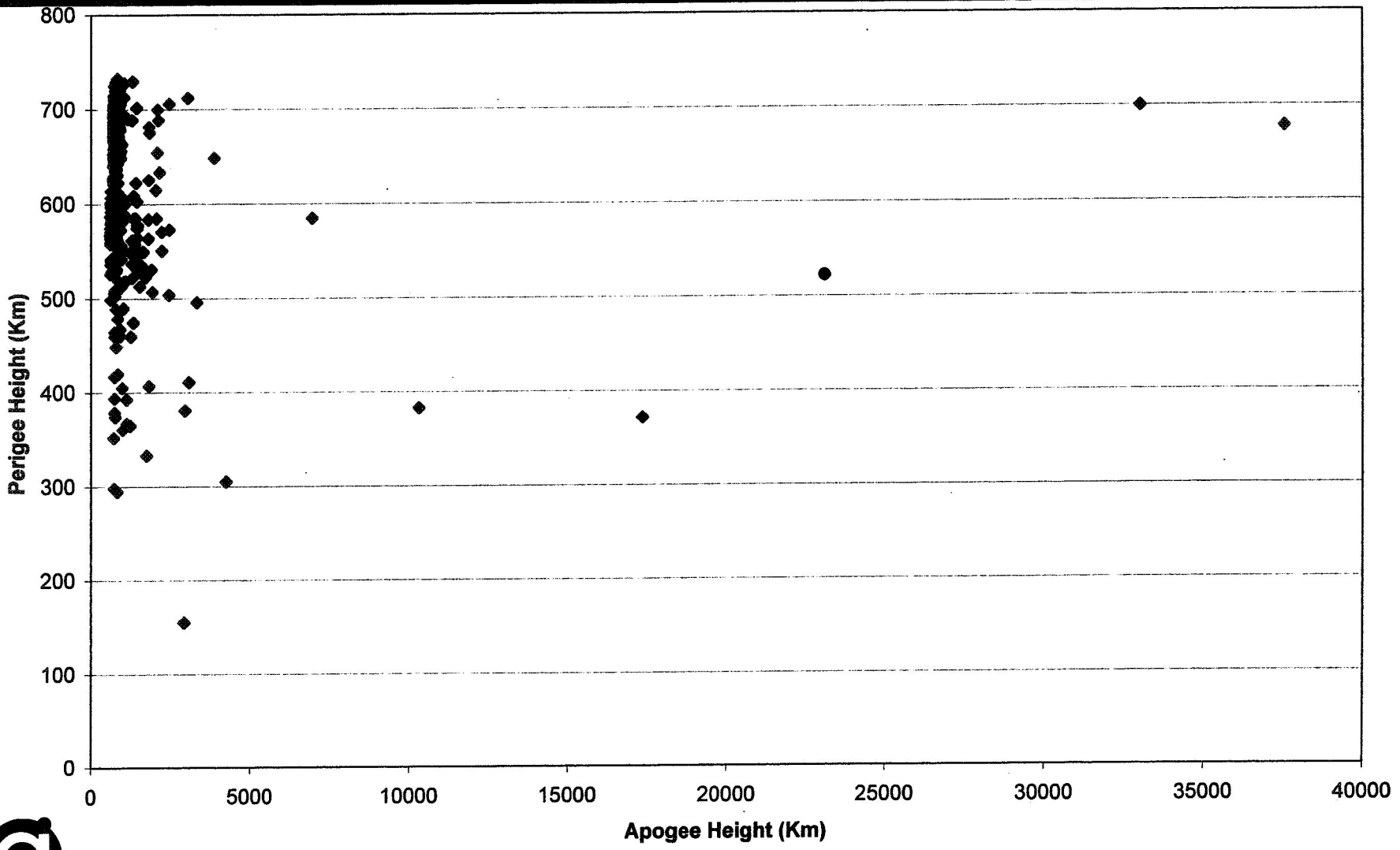
Apogee vs Perigee Height of Secondaries



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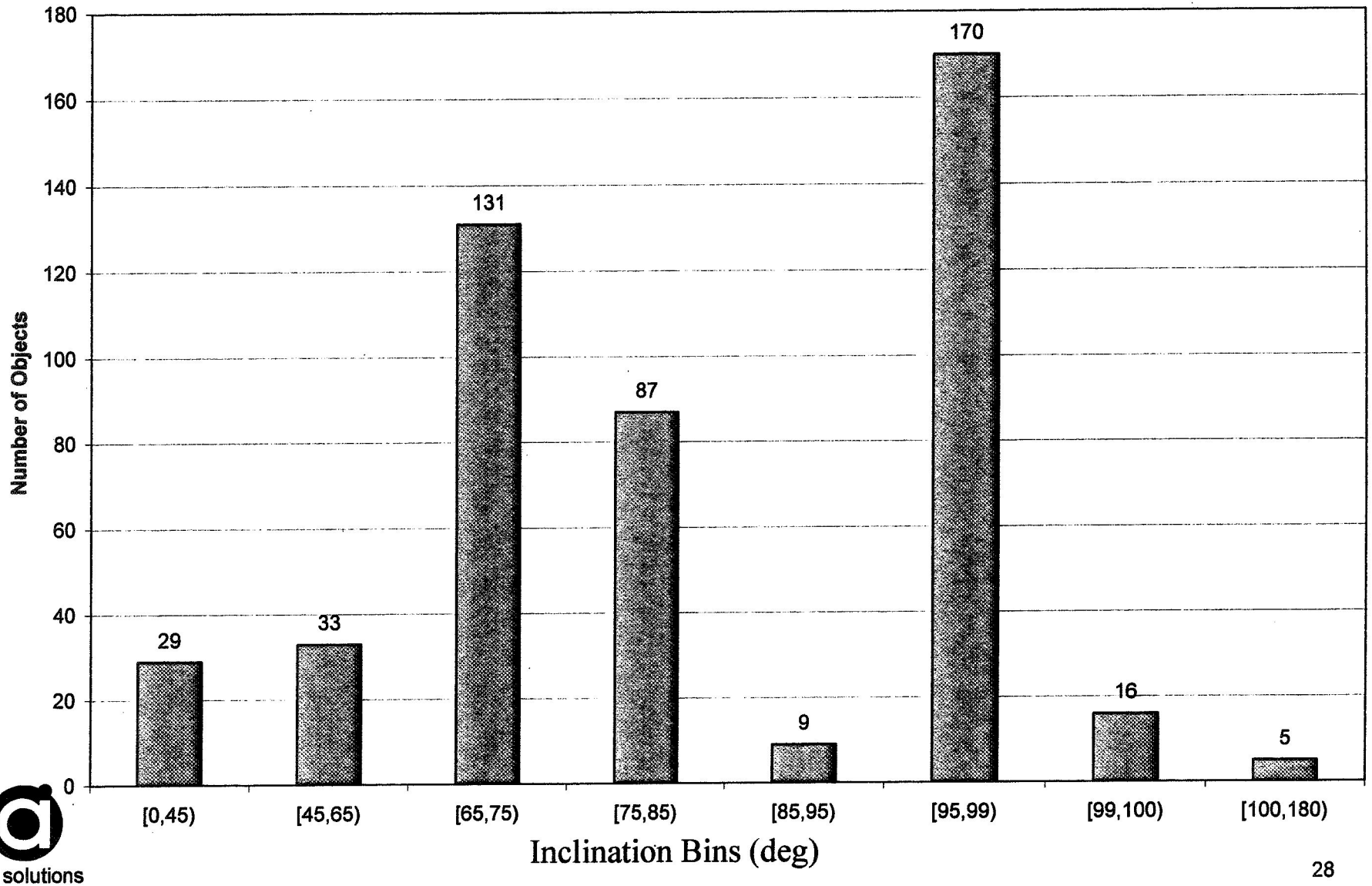
Inclination Distribution of Secondaries



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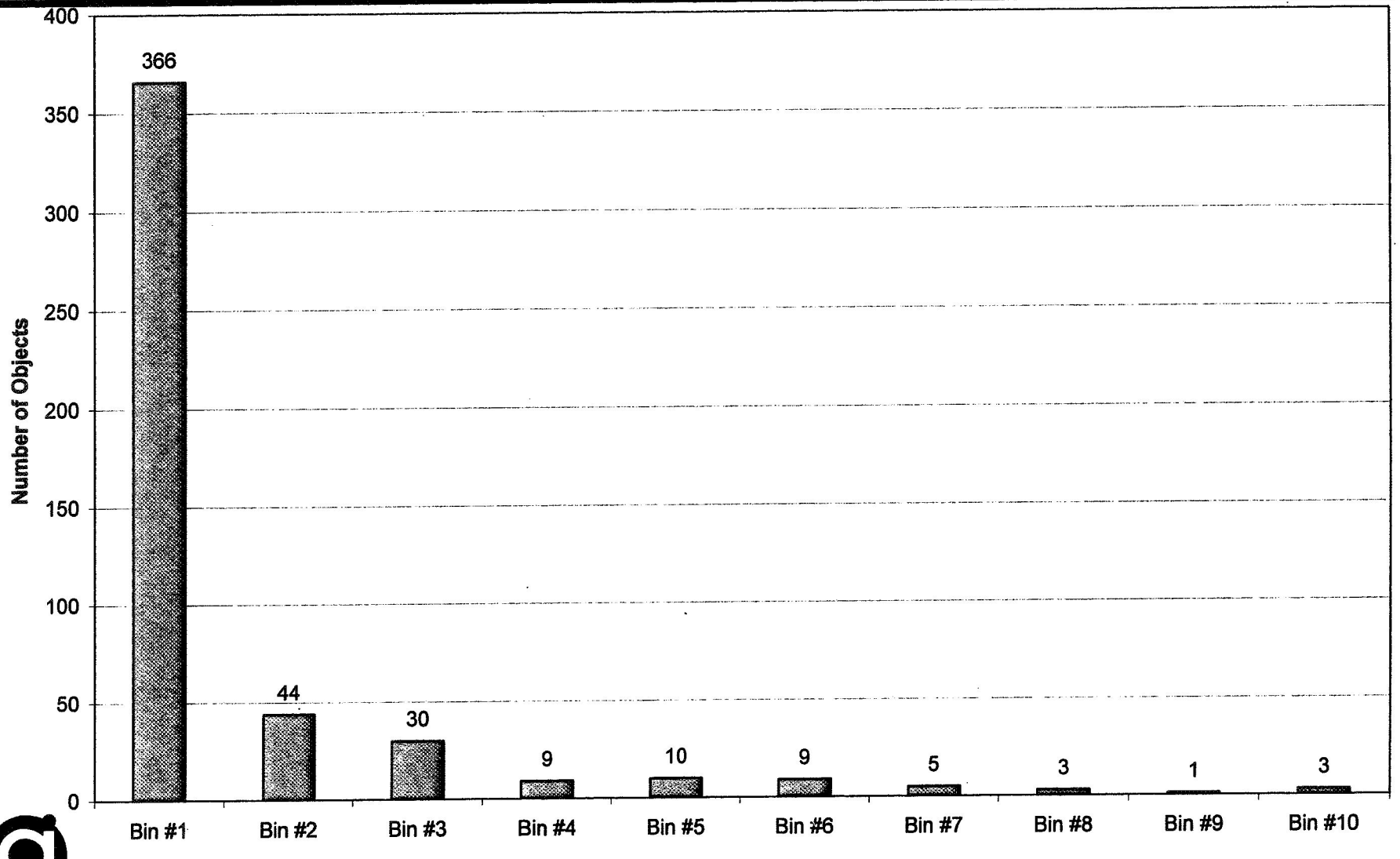
Secondary Object EDR Distribution (W/kg)



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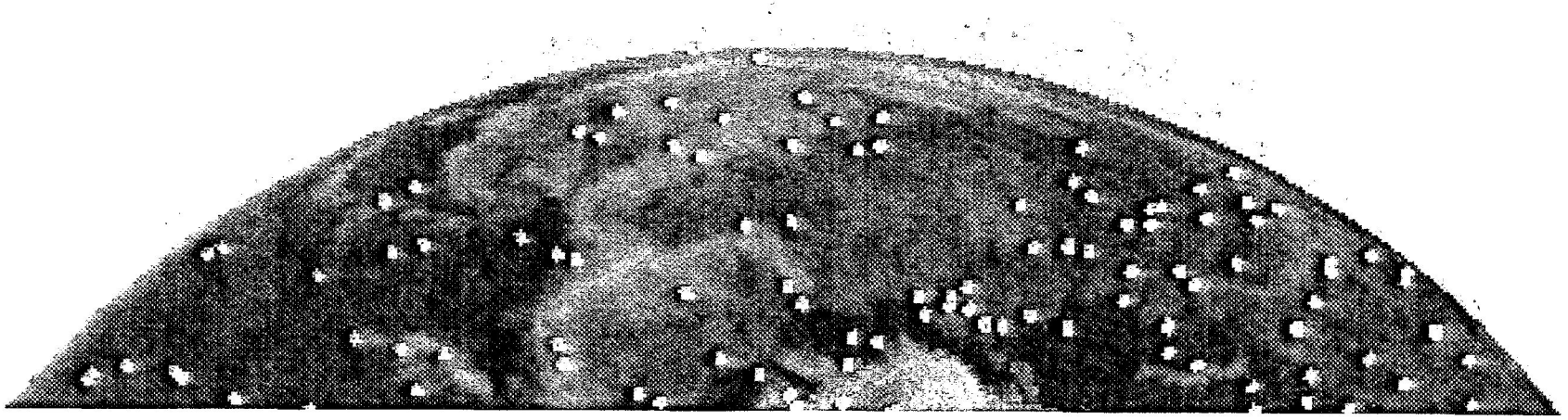
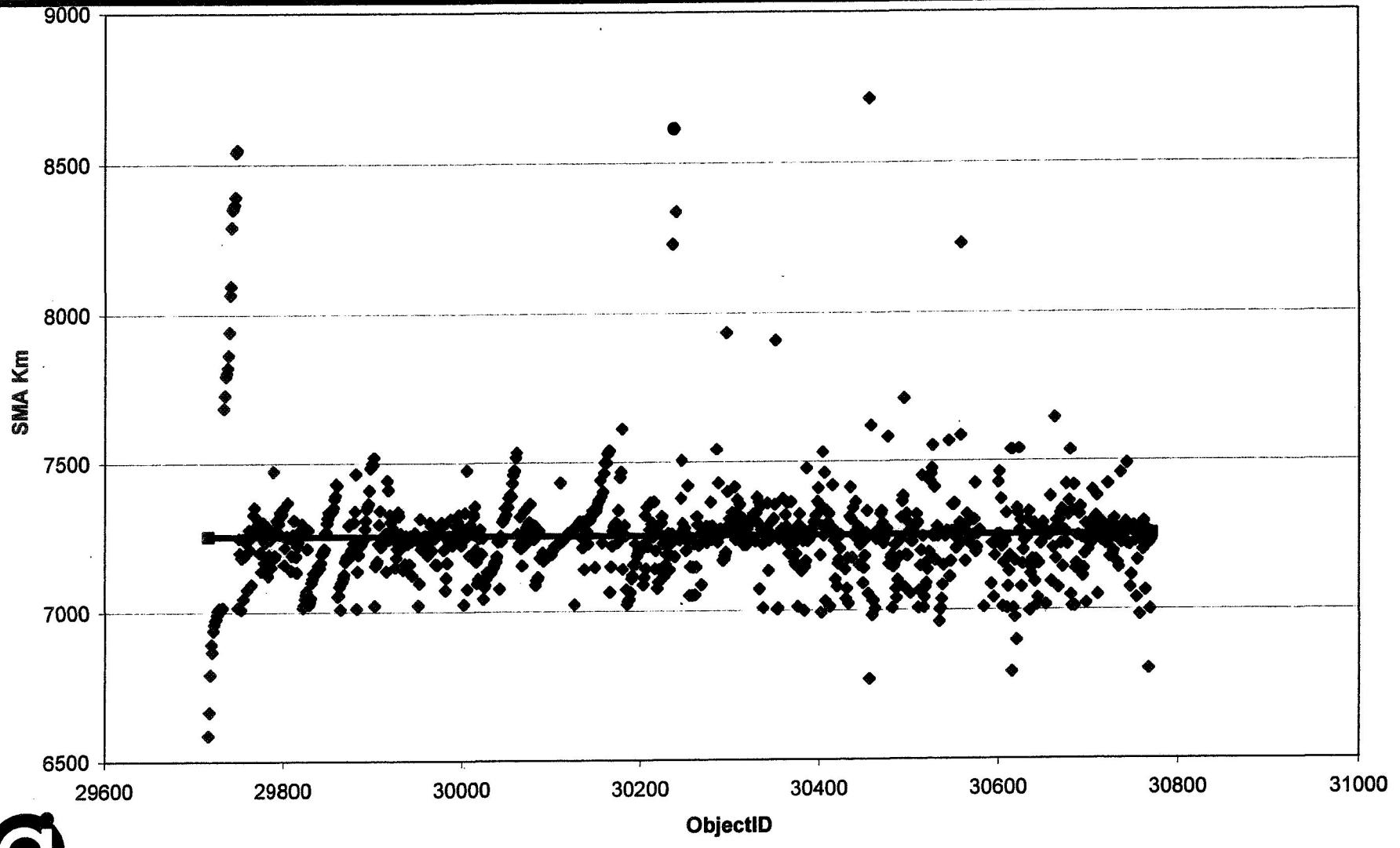
Chinese Debris Only



Fengyun 1C Debris SMA Distribution



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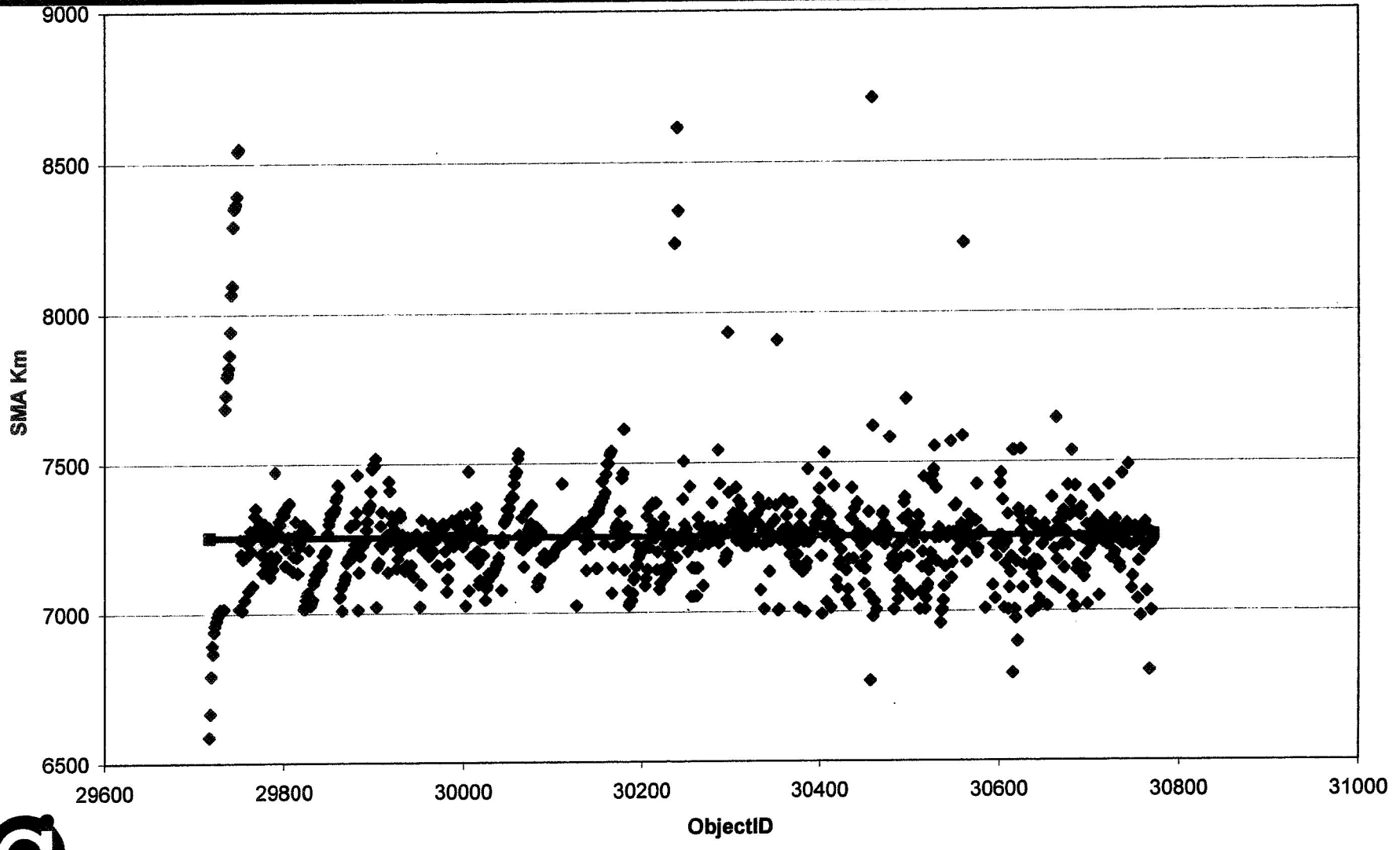
Fengyun 1C Debris SMA Distribution



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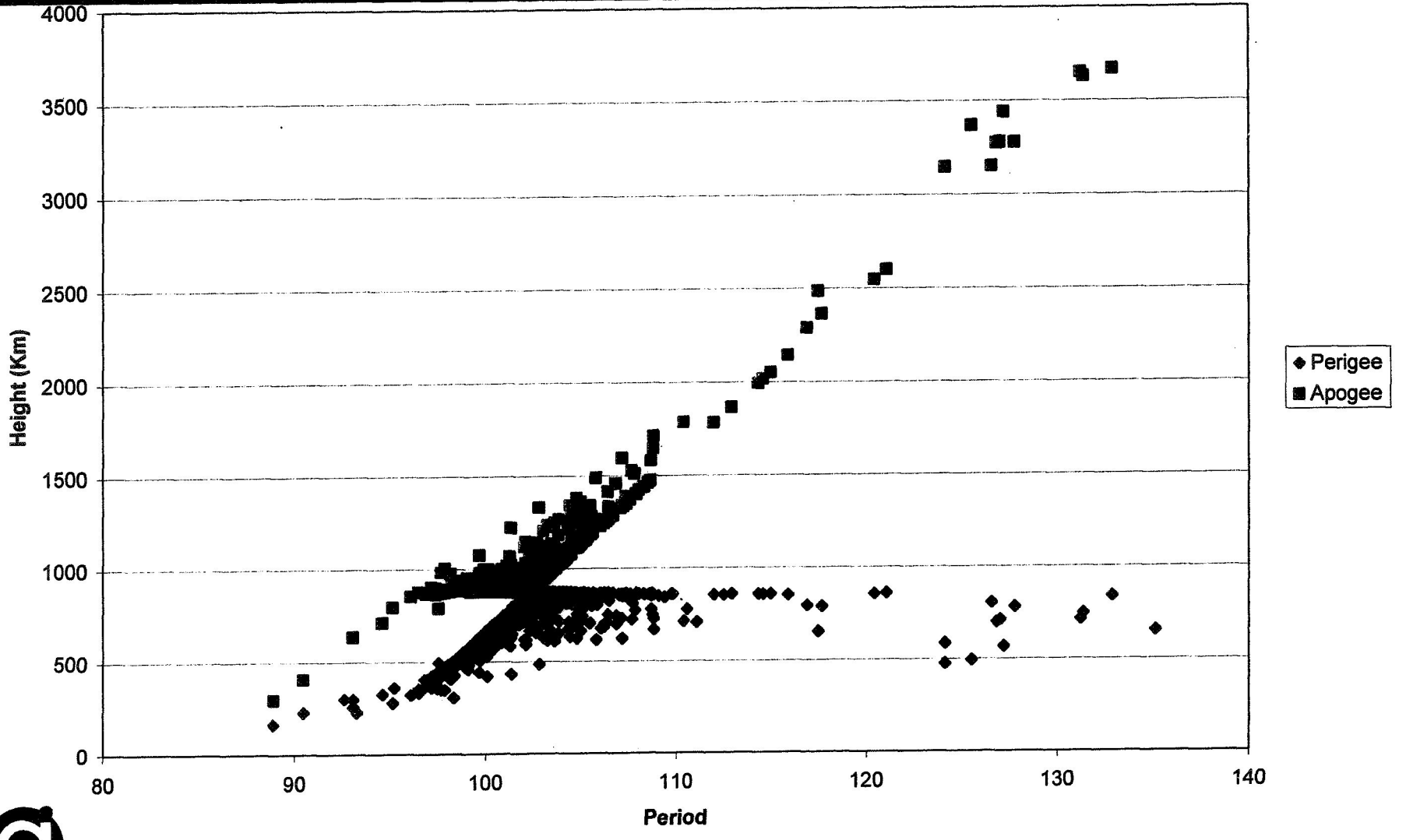
Fengyun 1C Debris Apsis Height vs Period



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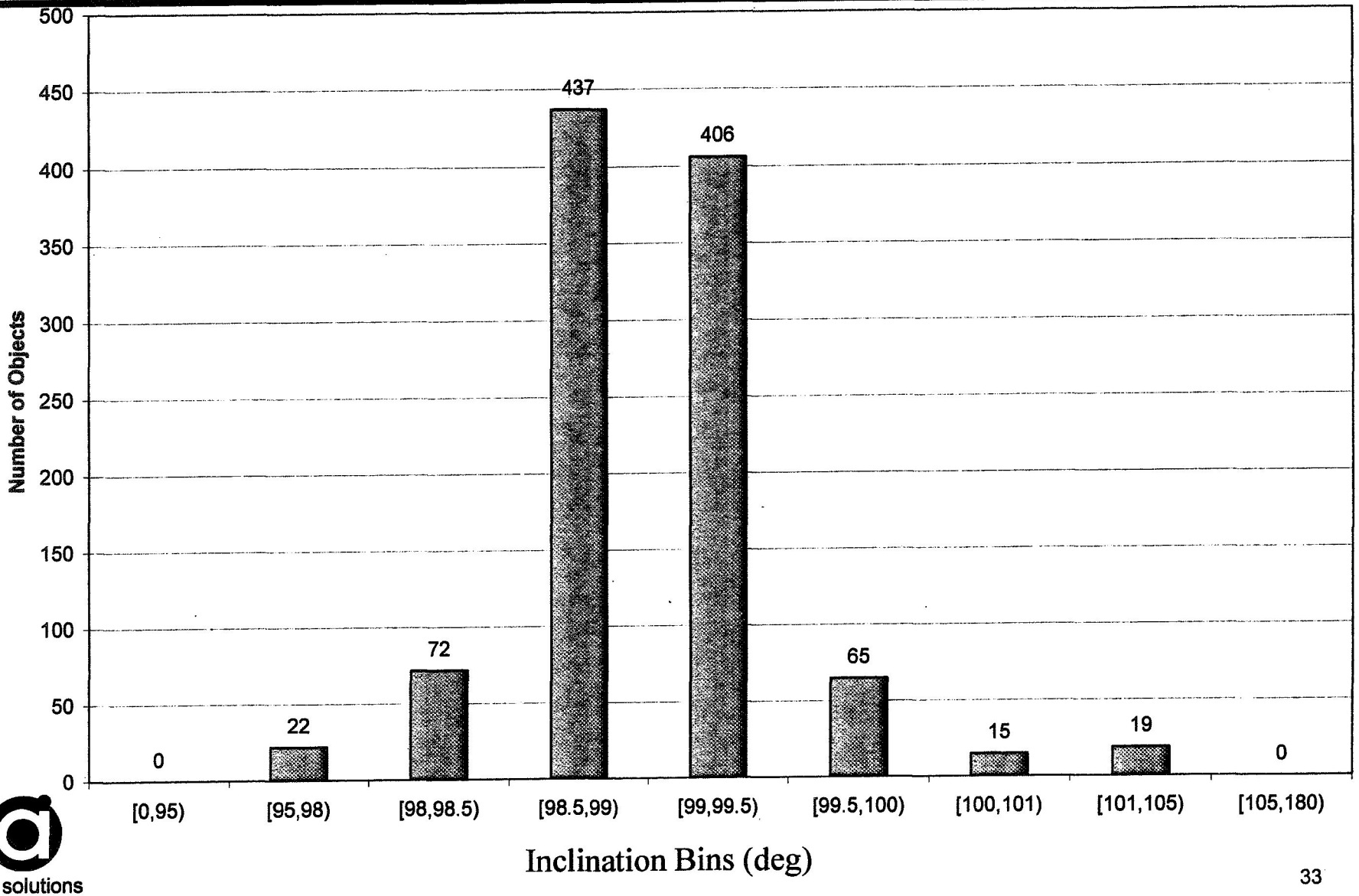
Fengyun 1C Debris Inclination Distribution



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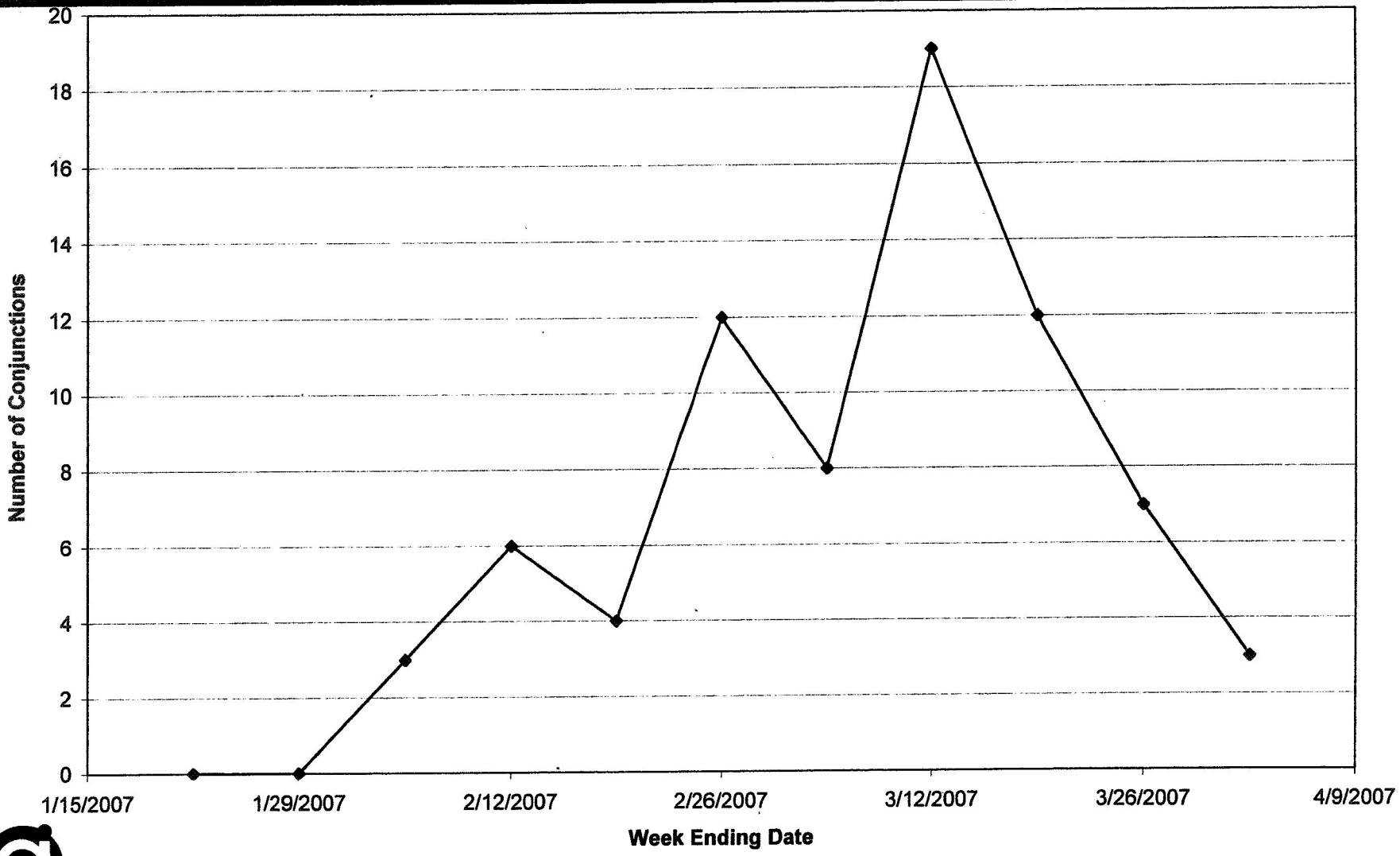
ESC Conjunctions with Fengyun 1C Debris



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Conclusions

- Have successfully mitigated threats to NASA Robotic assets using our process and tools
- Looking forward to partnering with AFSPC to exchange access to the pertinent data for results of analysis studies which would be performed for mutual benefit to our organizations.